Reliable Systems and Combined Heat and Power

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Abstract

Leading industrial companies and institutions are forever seeking new and better ways to reduce their expenses, reduce waste, meet environmental standards, and, in general, improve their bottom-line. One approach to achieving all of these goals is a 100 year-old concept, cogeneration or combined heat and power. Efficiency of cogeneration systems can reach 80 to 85 percent. Benefits of this throughout the plant include reliability enhancements and cost and emission reductions. Cogeneration schemes and systems can be modified to the plant design. The applicability of cogeneration to an industrial plant depends on the variations in steam and energy required for operation on both daily and yearly scales.

Cogeneration is receiving increased attention due to newer technologies that are making cogeneration opportunities available to smaller-sized thermal plants. Combined with electric utility deregulation opportunities, this is causing many industrial decision-makers to seriously consider cogeneration for their manufacturing plants. The advent of energy service companies has made financing of cogeneration projects attractive, helping to guarantee an acceptable return on investment.

Whether steam is created through cogeneration or separate generation, many opportunities exist to improve performance and productivity in steam generation, distribution, and recovery. These opportunities are captured by the systems approach promoted by programs such as the Department of Energy's (DOE) Steam BestPractices.

Introduction

Industrial and institutional plants need thermal energy, generally as steam, for manufacturing processes and heating. They also need electric power for motors, lighting, compressed air, and air conditioning. Traditionally, these fundamental needs are met separately. Steam is produced with industrial boilers and electricity is purchased from a local utility company. However, these needs can be met at the same time with cogeneration, using the same heat source and on a regional scale, greatly increasing the overall efficiency of energy generation.

Cogeneration is the concurrent production of electrical power and thermal energy from the same heat source. Large steam users commonly take advantage of cogeneration by using high pressure steam with a back pressure turbine to generate electricity, and extract lower pressure steam from the turbine exhaust for their process needs. This approach provides reliable energy while reducing their electric utility bills and providing thermal energy for industrial processes.

The steam turbine generators used by electric utilities require moderately high steam pressures and temperatures, with levels ranging as high as 4,400 psig. and 1,100° F respectively. This is expanded down to approximately 20 to 25 in Hg vacuum and 90° F to 100° F in the condenser, where the "latent heat of vaporization" is removed and discharged to the atmosphere, lakes, or rivers. Industrial processes are typically smaller systems using lower pressure and temperature levels, ranging down from approximately 1,000 psig. and 750° F to 150 psig. and 366° F (saturation temperature). The lowest heat intensity level processes are steam heating systems where pressures and temperatures of 15 psig. and 250° F are frequently utilized.

The Best of Both Worlds: Cogeneration

The steam generation cycle alone has a typical thermal efficiency of approximately 80 percent, depending on system loads, the fuel utilized, and the heat traps designed into the back-end of the boiler. Industrial boilers and utility boilers can achieve these efficiency levels while producing steam for their respective applications. Note that this efficiency level does not take into account the efficiency of the applications using the process steam or the efficiency of the steam distribution system.

Most utility thermo-electric steam power plants operate in the range from 30 to 40 percent efficiency depending on the throttle pressure and temperature, the number of reheater loops, the number of feedwater heaters utilized, and the type of heat traps utilized on the boiler. The gas turbine driven electric generator has historically operated in the high 20 to 30 percent range, but with today's high gas temperatures and compressor outlet pressures, the efficiency is ranging upwards of 35 percent. The latest utility power plant designs utilizing a combined cycle (a form of cogeneration) have high heat intensity gas power turbines exhausting into heat recovery boilers. Steam from these boilers then feeds a moderate heat intensity steam turbine generator. The combined operating efficiencies are in the 55 to 58 percent efficiency range. There are prototype designs being tested that exceed 60 percent.

However, modern industrial steam-electric cogeneration systems can boost overall thermal efficiency levels to an enviable 80 to 85 percent by recapturing enough waste heat from electricity-producing gas turbines to meet a portion of the industrial process requirements.[1] Typical non-industrial cogeneration users are college and university campuses, hospitals, municipal heating systems, and large commercial buildings. In addition to achieving high system thermal efficiency, steam-electric cogeneration systems can, if designed properly:

- Enhance the reliability of the power supply with on-site generating capacity to support operations during utility and electrical distribution line upsets.
- Reduce fuel costs by 15 to 20 percent by extracting more energy from the fuel when operating in the cogeneration format.
- Reduce or eliminate power purchases.
- Reduce overall emission levels from lower fuel use.
- Potentially provide additional revenue through sale of excess power to a district energy system or the utility electric grid.
- Maintain the high reliability of the single boiler process steam system by utilizing supplemental firing.

In terms of emissions and dollar savings, the difference between cogeneration and separate steam and electricity generation can be significant. Typically, cogeneration cuts fuel costs (which can range from 30 to 40 percent of the selling price of power) by increasing the amount of "salable product" per unit of energy.

Outlook

Cogeneration represents over half of all new power plant capacity built in North America in the last 10 years. This includes utilities and independent power producers (IPPs) as well as cogeneration by industrial companies and institutions. As of 1994, it accounted for 6 percent of total U.S. electricity-generating capacity. Of the electricity actually generated, 9 percent came from cogeneration.

Deregulation of the electricity market could open the door for renewed growth in cogeneration, but lots of potential utility and permitting-barriers still remain. Lower demand for electricity and increased utility resistance to industrial cogeneration are expected to diminish the prospects of seeing any new incentives for installing cogeneration.[2] However, utility deregulation and increasing concern about climate change are raising questions relative to the long-term availability and reliability of conventional power. These concerns and the availability of new low-cost generating technologies have piqued the interest of industrial and commercial customers with high thermal loads, high electricity rates, or both.

The deregulation opportunity is expected to present itself in two important areas: increased competition and increased marketability of low cost cogeneration-produced electricity. Increased competition in the electric market will result in lower electricity rates, which could make it more difficult for cogeneration projects to compete with larger utility companies. Again, this difficulty will vary across the country as electricity rates vary. Marketability of cogenerated power will increase because cogenerators will be able to sell excess power to customers other than their local utility. That means industrial cogenerators will be able to sell electricity to the public, to other industrials, to power brokers, and to distribution companies by wheeling it to them through the local utility's distribution system. Retail wheeling will be especially attractive in areas with very high electricity rates.

Types of Cogeneration Systems[3]

There are three basic types of cogeneration systems, categorized by the "prime mover" of the system: engine-based, steam turbine-based, and gas turbine-based. Each is briefly characterized below.

Engine-based System

Engine-based systems use an internal combustion engine to power a generator. Waste heat is reclaimed by sending exhaust to a steam generator, and by extracting heat from the engine and oil cooling systems. Since engine-based systems are only capable of producing low-pressure steam, they cannot be used by industries requiring pressure over 30 psig.

Of the three major types of cogeneration, engine-based systems possess the highest power-to-steam ratio.

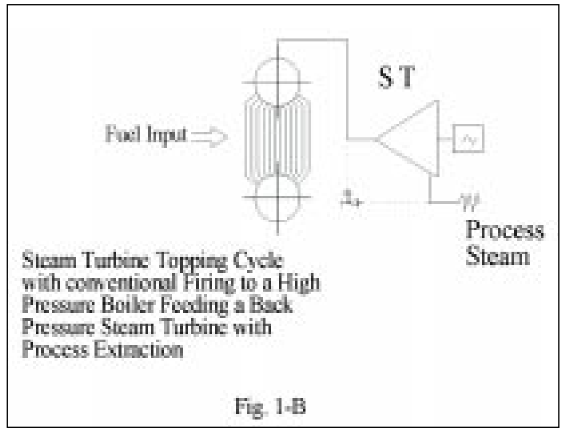
- Power-to-steam ratio: > 1.
- Size range: 10 kW – 16 MW; Typical size: 1 MW.
- Usable fuels: Gasoline and oil.

Unfortunately, engine-based cogeneration systems suffer from frequent breakdowns, thereby raising their operating and management costs, and increasing the costs of firm power back-up from local utilities. However, they have fairly low capital costs, simple operating and repair procedures, and good load-following ability. In terms of emissions, diesel engines produce substantial amounts of nitrous oxide (NO_x) and particulates while natural gas engines emit unburned hydrocarbons. Both types, however, emit low amounts of carbon monoxide (CO) and sulfur dioxide (SO_2).

Steam Turbine-based System

The steam turbine-based system relies on a conventional boiler to generate high-pressure steam. The high-pressure steam is then expanded across a high pressure turbine and the exhaust is routed to the process steam header. The high-pressure turbine generates electricity while functioning simply as a pressure reducing valve, providing the

Figure 1: Boiler with Backpressure Turbine



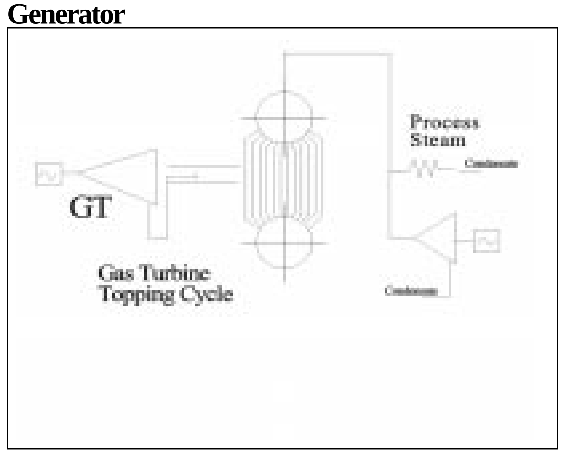
desired steam conditions to the process or heating system. The electrical power is generated at very high levels of thermal efficiency (95 to 96 percent) as there are no losses to the condenser. This is referred to as a backpressure turbine (see Figure 1).

- Power-to-steam ratios: 0.1-0.2.
- Usable fuels: Gas, coal, oil, natural gas, biomass, wood, municipal solid waste, or industrial waste.
- Size range: 10 kW – 400 MW, Typical size: 10 MW.

Back-Pressure Steam Turbine-Systems

These systems are good producers of heat, but low power producers. Therefore, they are particularly useful where large amounts of steam (a large thermal load) and moderate amounts of electricity (a low electric load) are needed. This system also allows for large electrical drive motors to be re-

Figure 2: Gas Turbine with Heat Recovery Steam Generator



placed with back-pressure turbine drives, thereby replacing electrical consumption with steam at approximately 90 percent efficiency. The steam turbine drives are durable, reliable, and good load-followers. Overall emissions depends on the fuel used to fire the boiler. Coal and biomass produce NO_x, SO_x, and particulates, while oil and natural gas produce CO and NO_x.

Gas Turbine-based System

Gas turbine systems use a conventional combustion turbine to generate electricity. After electricity is generated, the exhaust from the gas turbine is fed to a thermal process, such as a heat recovery steam generator, to produce steam (Figure 2).

- Power-to-steam ratios: 0.6 - 1.0.
- Usable fuels: natural gas and oil.
- Size range: .02 MW - 300 MW
- Typical size: 5 MW.

Gas turbines efficiently produce power, steam, and heat in concert and are, therefore, very attractive for cogeneration uses. However they require a high-quality fuel, are poor load-followers, and their technical complexity requires specially-trained staff to maintain them. In place of in-facility staff, smaller units can be offered with maintenance contracts and spare units kept available for quick changeouts.

Various elements of these systems can be combined depending on power and steam needs. For example, a combined-cycle gas turbine system could divert available steam to turn a steam turbine for more electricity, which can boost the power-to-steam ratio to the 1.5 range. Thus, when the process thermal load is down, the steam can be used for peaking power.

Is Cogeneration Right For You?

With today's technology developments in small gas turbines, along with the use of supplemental firing to support thermal peak loads swings, cogeneration is an economical and practical choice for small energy users as well as the large process industry users. As cogeneration attracts a larger base of applications, potential for improved energy efficiency and reduced environmental pollution increases. The DOE recently launched the Industrial Combined Heat and Power (CHP) Initiative to further enhance the adoption of cogeneration and related systems.

Characteristics of Facilities Well-Suited for Cogeneration

Industries that use consistent, simultaneous quantities of both electricity and steam with relatively high energy costs are the best candidates for cogeneration adoption. These often include food processing, chemical manufacturing, primary metals, commercial laundries, drywall manufacturers, and paper mills. Demand for both steam and electricity should be year-round and have an acceptable mix of loads over the course of a day. The key to success of these systems is the ability to match the size and loads of the combined electric and steam systems.

"This [cogeneration] project is an important step in increasing the overall efficiency and cost effectiveness of the operation at the Hawkins Point Plant." ***-John Davis, Millennium Chemical***

A perfect fit is not likely to happen, and the system must be properly sized and engineered to achieve maximum efficiency, reliability, and operability. Numerous combined cycles have looked quite good on paper, only to fall short of their goal because the load requirements of the two systems didn't match as planned. Options in proper management of steam facilities include:

- Business as usual.
- Maintaining the status quo with implementation of best maintenance and operation practices.
- Upgrading to a cogeneration system.
- Outsourcing energy decisions to a third-party such as an energy services company.

Websites with more information on cogeneration include www.oit.doe.gov/chpchallenge and www.nemw.org/uschpa.

Systems Thinking

When considering which option to take, "systems" thinking offers the most advantageous way to operate a plant. Systems thinking applied to a facility involves looking at the overall plant resource and energy consumption and production to determine the areas in greatest need of optimization. It also applies to looking at systems individually. In incorporating systems thinking, it is useful to use The Natural Step (TNS).[4] TNS guides businesses in developing for their long-term future. It has a framework based on simple thermodynamic principles and has developed several tools as guides. One of these tools, the Compass, entails:

1. Visualizing how you would like to be operating decades into the future.
2. Assessing your current inputs, outputs, and operating practices.
3. Formulating a path to help you achieve this desired level by changing practices, policies, and operations.

This provides direction to the company as a whole. The same principle applies to energy systems. First, visualize how the steam system should be operating. Second, assess current operation. And third, identify the areas for improvement and the resources which allow them to be changed.

Cogeneration can be an integral part of the path to the ideal state of operation. However, the current state of practices and operations must already be conducive to making the move to cogeneration.

BestPractices

Systems thinking and identification of areas of improvement can often be difficult. Fortunately, a clearinghouse of resources has been established for steam system management. BestPractices Steam resources, offered by the DOE's Office of Industrial Technology (OIT) in conjunction with the non-profit Alliance to Save Energy, encourages a systems perspective that views individual energy-consuming components as part of a total system, focusing on the entire plant where significant savings can be found. Resources include tip sheets, case studies, lists of training courses, technical references and standards, assessment tools, and operational handbooks. These are available on-line or through the Industries of the Future (IOF) Clearinghouse.

What is BestPractices?

BestPractices brings together the best-available and emerging technologies, and practices to assist industries to improve their competitive position, of which steam is one component. Through the BestPractices approach, industry has easy access to both near-term and long-term solutions for their total manufacturing plant operations today. Any plant can realize near-term cost-effective energy savings between 10 to 30 percent in three to five years. By applying the best technologies and practices available, industry can:

- Prioritize energy efficiency investments for the greatest return on investment.
- Receive training, tools and documents to help implement projects.

The Industries of the Future Clearinghouse has more information on how to begin implementation of best practices.

Participation in BestPractices Steam efforts is open to steam system operators and managers, developers and distributors of steam systems equipment, as well as steam trade and membership organizations. This active participation ensures that BestPractices provides tools and resources that are valuable to industrial steam operators and managers. It also assists steam equipment and service providers, such as utilities, distributors, manufacturers, consulting engineers, and others promoting steam efficiency by serving as a valuable source of third-party, credible information.

Conclusion

With cogeneration achieving efficiency levels over 80 percent, fuel costs and emissions are lowered and additional profits are available from the sale of excess power. Advanced design and new technology has lowered generation capacity tremendously, to the point where even small plants can feasibly install cogeneration facilities. Cogeneration combined with the energy delivery improvements suggested by BestPractices Steam increases these benefits even more. However, before installing a cogeneration system there are several screening factors to be considered, including individual thermal profile, initial capital outlay, permitting standards, and readiness to be in the power provider business. Existing steam system components which support cogeneration equipment must be running as efficiently as possible. BestPractices Steam helps prepare industry for future cogeneration. In addition, the same wealth of benefits accrues for improved environmental and economic performance. While the future of cogeneration in states' deregulation remains hazy, it will continue to be a "power"ful generation option.

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References

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2. 1997 Industrial Cogeneration Report, Chapter 2, Gas Research Institute, Chicago, IL.
3. Ibid.
4. TNS is a movement dedicated to helping understand our social and environmental problems and moving beyond them by redesigning our interactions with our surroundings as businesses, communities, and individuals.